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Acoustic Emission/Flaw Relationship for In-Service Monitoring of Nuclear Pressure Vessels

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April 1985 - September 1985

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Prepared by P. H. Hutton, R. J. Kurtz

Pacific Northwest Laboratory
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Acoustic Emission/Flaw Relationship for In-Service Monitoring of Nuclear Pressure Vessels

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ABSTRACT

This report discusses technical progress for the period April 1985 to September 1985 under the NRC-sponsored research program concerned with "Acoustic Emission/Flaw Relationships for Inservice Monitoring of Nuclear Reactor Pressure Boundaries." Topics discussed include testing AE monitoring on operating reactors, refinement of an AE signal identification relationship, developing AE/IGSCC relationships, evaluating the effects of slow crack growth rate on AE generation, and activities to produce an AE monitoring standard and acceptance of the technology by the ASME Code.

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ACOUSTIC EMISSION/FLAW RELATIONSHIP FOR IN-SERVICE MONITORING OF NUCLEAR PRESSURE VESSELS[a]

P. H. Hutton, Project Manager
R. J. Kurtz, Assistant Project Manager

SUMMARY

Preparations for AE monitoring startup and subsequent operation of the Watts Bar Unit 1 Reactor are completed awaiting reactor fuel loading. In addition, negotiations are in process to arrange for AE monitoring a section of primary piping in a reactor with a known crack during an operating period.

Testing continues to substantiate the pattern recognition method developed under this program for identifying AE signals from crack growth. It has been shown to be capable of separating AE produced by crack growth from data produced by oxide cracking.

Work is in progress to determine AE characteristics of IGSCC in stainless steel piping.

Testing has been initiated to evaluate AE produced during slow crack growth rates (10^{-7} inches/second) in A533B steel.

An ASTM standard for guidance in applying AE to continuous monitoring of pressure systems has been submitted to the E07.04 Subcommittee for balloting.

INTRODUCTION

The objective of the acoustic emission (AE) monitoring program is to develop and validate the use of AE methods for continuous surveillance of reactor pressure boundaries to detect flaw growth. The benefits expected from the program include:

- Increased assurance of physical integrity of the pressure system under both normal and abnormal operating conditions by early detection of cracking.
- Provide a means for continuously evaluating the condition of primary pipe welds and weld repairs.

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[a]Work supported by the U.S. Nuclear Regulatory Commission under Contract DE-AC06-76RLO 1830; FIN. B2088; NRC Contact: Dr. J. Muscara.

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- In conjunction with work at Argonne National Laboratory, provide the capability for early detection and characterization of coolant leaks.

The program has followed a planned format of developing basic AE/crack growth relationships in the laboratory; evaluating and improving these relationships through testing an intermediate scale pressure vessel; and demonstrating the technology by continuously monitoring a reactor(s) during operation.

Initial laboratory testing and vessel testing have been completed. The emphasis is now on reactor monitoring demonstration and on developing standards and code acceptance in support of technology transfer for beneficial use.

TECHNICAL PROGRESS

Technical progress is reviewed under the following topics:

- Reactor monitoring
- AE signal pattern recognition
- Development of IGSCC/AE relationships
- Slow crack growth rate/AE evaluation
- Standards and codes

REACTOR MONITORING

AE monitoring activities at Watts Bar Unit 1 Reactor are on hold awaiting the start of fuel loading. As discussed in the last progress report, all instrumentation is in place on the reactor (sensors, preamplifiers, and cabling), and the monitor instrument is ready to be installed. Currently, fuel loading is projected to start in January 1986 at which time the monitoring instrument will be installed.

In addition to the Watts Bar activities, active negotiations are in progress to arrange for installation of an AE monitor system on inservice piping to monitor IGSCC growth during reactor operation. The potential locations are Millstone 1 and Peachbottom 3. This work has the objective of monitoring a location(s) with known cracking which will be left unmodified for the next operating period. Since some crack growth would be expected to occur, this provides the opportunity to demonstrate the capability of AE monitoring to detect crack growth in piping during reactor operation. Successful accomplishment of this objective addresses not only safety but also economics in the sense that it could provide the basis for continuous surveillance

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of pipe weld repairs to assess their integrity over an extended period of time.

PATTERN RECOGNITION

The AE signal pattern recognition method developed for this program is based on the unique response generated in a thin rod (a metal waveguide sensor) when energy in the form of a half-cycle shock pulse (AE signal) impinges on one end. Figure 1 shows the form of the energy wave projected from cracking as measured at Harwell Laboratory in the U.K. NBS has independently shown similar results. Three distinct propagation modes are set up in the waveguide, which in turn produce a unique output from a sensing crystal on the end of the waveguide. Other types of multi-cycle signals do not produce such a response in an identifiable form.

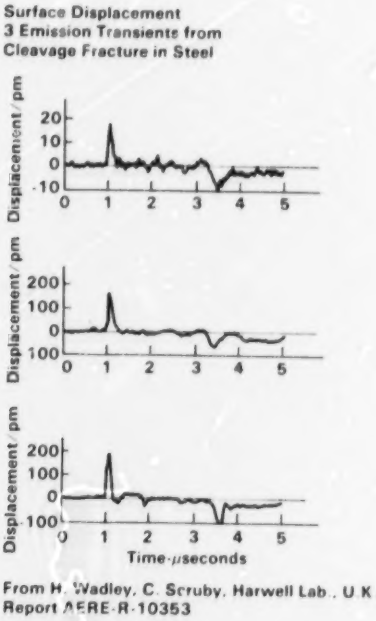

Figure 1. Acoustic Emission Energy Waveform from Cracking as Transmitted through the Material

The method is being tested and evaluated on a continuing basis. In the high temperature portion of the ZB-1 intermediate scale vessel test, one of the hydro tests was performed after the vessel had been open to the air and surface oxide had formed on the inside surface. During the first step of the hydro test, essentially all of the acoustic data produced came from cracking of the surface oxide. This provided a challenging

test for the pattern recognition method to see if it confused this information as being from crack growth in the metal. Acoustic waveforms were recorded in digital form throughout the ZB-1 test. One hundred fifty of these waveforms from the period of oxide cracking during the hydro test were processed by pattern recognition. They were classified as not being crack-related AE. Figure 2 shows the distinct difference between the two types of signals. A possible explanation of the differ-

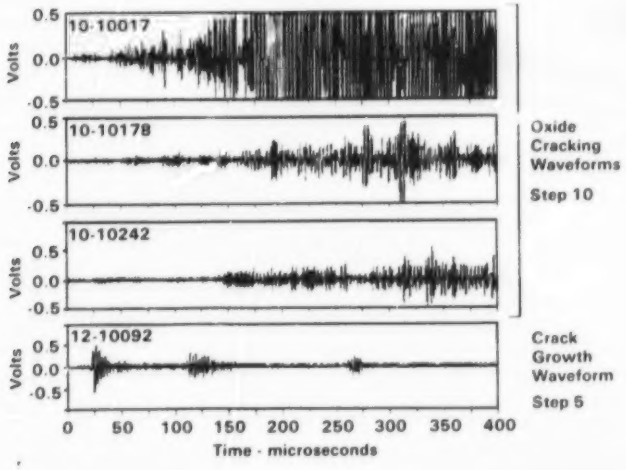

Figure 2. Comparison of Acoustic Signals Detected from Oxide Cracking Vs. Metal Crack Growth - ZB-1 Test.

ence lies in the fact that, although the oxide cracking is a brittle fracture process, it does not occur in micro increments; i.e., a significant length of the oxide will crack almost instantaneously producing a series of very closely spaced signals that will not produce the identifiable signal separation in the waveguide.

AE signal pattern recognition has been implemented in the prototypic AE monitor system to be used at Watts Bar Unit 1 for operational monitoring. Figure 3 gives the basics of the approach used. When the system is triggered by an incoming acoustic signal, it holds for a time period to allow the first pulse of a crack-growth AE signal to decay. It then counts for a period to check for signal above threshold between the first and second pulse where there should be none. A second count period is then started to determine if the second pulse is present. This process is then repeated to determine if the third pulse is present. In this mode, signals are processed in real time and flagged if they are determined to be crack-growth AE signals - no waveform recording is required. At this stage, no data is discarded but as the AE signal identifi-

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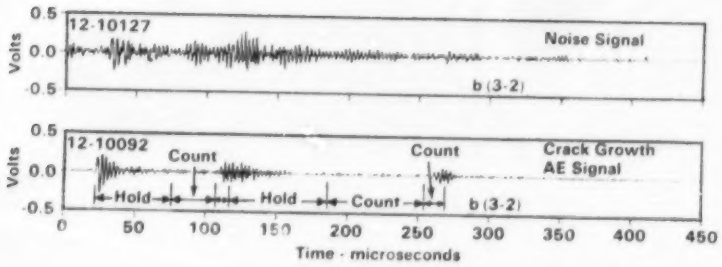

Figure 3. AE Signal Pattern Recognition Implementation.

cation method is more positively substantiated, only data identified with crack growth would be retained.

DEVELOPMENT OF IGSCC/AE RELATIONSHIPS

Two 4-inch, Schedule 80, Type 304 stainless steel pipe specimens were started in IGSCC testing in May 1985. Residual stress is estimated to be in the 17 to 29 ksi range, and the EPR sensitization measurements are shown in Figure 4. One of the specimens installed in the test facility is shown in Figure 5. Both specimens are loaded to 13.5 ksi externally plus 4.5

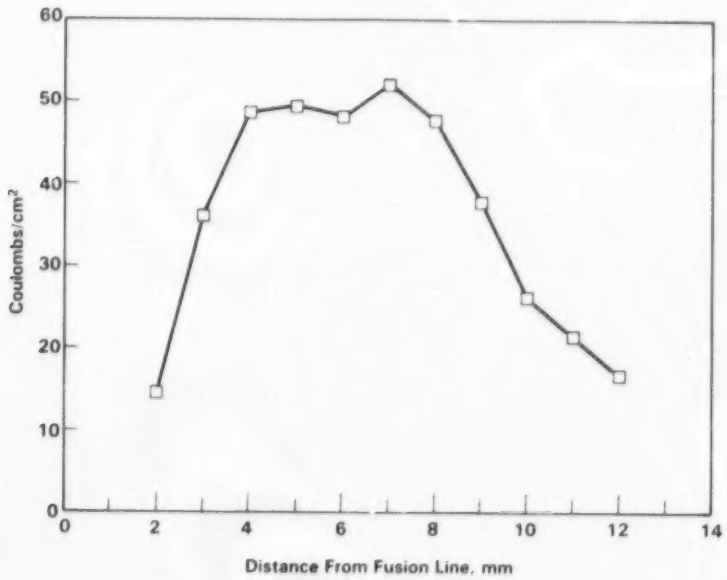

Figure 4. EPR Measurements on IGSCC Test Specimen.

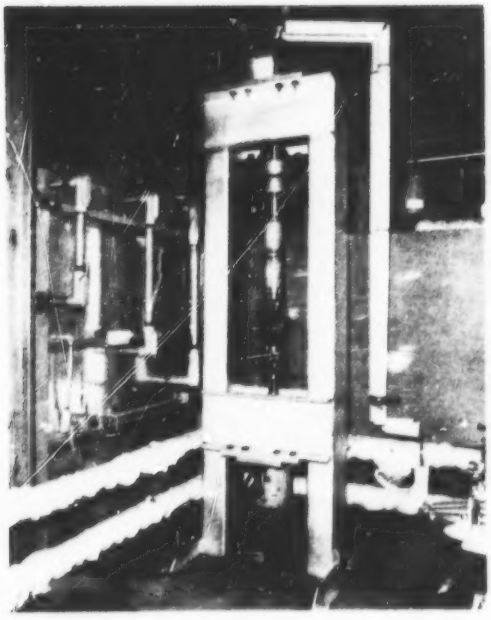

Figure 5. IGSCC Specimen Installed in Test Facility.

ksi from internal water pressure. Water at 550°F containing 30 ppm oxygen is circulated through the specimens. External load on the specimens is cycled once per week. There is some evidence from the AE that cracking may be starting.

Acoustic signal waveforms are being recorded for the purpose of testing the effectiveness of the AE signal recognition technique, discussed above, in identifying signals from IGSCC. By recording the signals instead of doing real-time signal analysis, the option of examining misclassified signals to learn why they were misclassified is retained.

Another feature of the test is evaluation of utilizing continuous potential drop measurements to track the growth of an IGSCC crack. The method being applied is one being developed by AT&T Bell Laboratory. If successful, this could be a valuable technique for laboratory testing and also potentially for field use.

SLOW CRACK GROWTH RATE/AE EVALUATION

Reduced AE at low crack growth rates (1×10^{-7} inches per second) during the ZB-1 vessel test suggested the need for additional investigation to evaluate AE generation at very low crack growth rates. A laboratory test is in progress to study

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the AE/crack growth relationship at crack growth rates in A533B steel ranging down from 1 x 10^{-6} inches per second. Table 1 shows the test matrix. This matrix covers a range from the

Table 1. Test Matrix for Low Crack Rate Test

Crack Length	ΔK	da/dN	Δ Time (hours)
1.8	14.9	1.1×10^{-6}	25
1.9	13.6	8.9×10^{-7}	31
2.0	12.5	7.1×10^{-7}	39
2.1	11.5	5.7×10^{-7}	49
2.2	10.7	4.7×10^{-7}	59
2.3	9.8	3.7×10^{-7}	75
2.4	9.1	3.0×10^{-7}	93
2.5	8.5	2.5×10^{-7}	111
2.6	7.9	2.1×10^{-7}	132
2.7	7.4	1.8×10^{-7}	154
2.8	6.9	1.5×10^{-7}	185
2.9	6.4	1.2×10^{-7}	232
3.0	6.0	1.0×10	278

R = 0.7

low end of crack growth rates studied in the laboratory down to the lowest values experienced in the ZB-1 vessel test. The single edge notch test specimen (Figure 6) is 1-inch thick with a 6- x 18-inch test section. Several sets of AE sensors

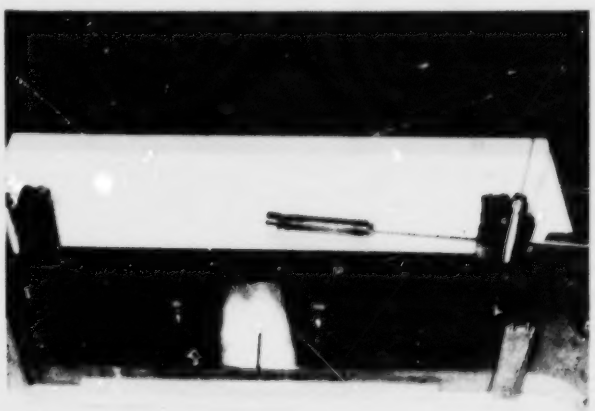

Figure 6. Slow Crack Growth Test Specimen.

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are being used. Surface-mounted conventional sensors are placed near the crack on either side to provide a base reference of detectable AE from the growing crack. Waveguide sensors, both pressure coupled and mounted in drilled and tapped holes, are used on the flat and on the edge of the specimen. This combination will evaluate the penalty in detection sensitivity in going from threaded waveguides to pressure coupled waveguides and whether the planar orientation of the waveguide relative to the crack influences AE detection. Finally, it will provide a gauge of the AE detection capability to be expected from pressure coupled waveguide sensors at low crack growth rates on a reactor.

Since the test is just started, no significant data has been generated yet. The notch precracking process was AE monitored, and the AE was detected as expected for this relatively high crack-growth rate period.

STANDARD AND CODE WORK

A "Standard Practice for Continuous Monitoring of Metal Pressure Boundaries Using Acoustic Emission" has been submitted to the ASTM E07.04 Subcommittee on Acoustic Emission for balloting. This standard provides a guide for applying AE methods for integrity monitoring of pressure boundaries.

Approval of continuous AE monitoring by the ASME Section XI Code is critical to beneficial use of the technology on nuclear reactors. The major need for favorably influencing code committees is engineering data demonstrating that the AE technique developed under this program is effective. Hopefully, the reactor testing described earlier will provide the needed data. Arrangements have been made to describe results achieved under this program to the Section XI Code Committee at the February 1986 meeting.

REPORTS

- NUREG/CR-4300, Vol. 1, "Acoustic Emission/Flaw Relationship for In-Service Monitoring of Nuclear Pressure Vessels, Progress Report, October 1984-March 1985." Published August 1985.

- NUREG/CR-3915, "Acoustic Emission Results Obtained from Testing the ZB-1 Intermediate Scale Pressure Vessel." Published September 1985.

FUTURE WORK

- Initiate AE monitoring on an operating reactor.
- Test AE signal identification method in separating crack interface noise from crack growth AE.
- Continue AE characterization of IGSCC.
- Evaluate effects of slow crack growth rate on AE generation.
- Continue standard and code work.

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